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STATE OF CALIFORNIA
The Resources Agency

Department of Water Resources

BULLETIN No. 144-68

RADIOLOGICAL APPLICATIONS PROGRAM

Annual Report for FY 1967-68

SEPTEMBER 1968

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Administrator
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FOREWORD

This is the first report in the Bulletin No. 144 series. It covers activities of the Department of Water Resources' Radiological Applications program from its inception in 1958 through the 1967-68 fiscal year. Subsequent reports will be published annually by the Department for the use of all interested agencies and the general public.

The term "radiological" pertains to the study and use of atomic energy in the form of radioactive isotopes and X-ray apparatus. The radiological applications program of the Department was initiated in 1958, pursuant to House Resolutions 88 and 234, 1957 California legislative session. H. R. 234, among other provisions, directed appointment of a Subcommittee to ascertain, study, and analyze all facts relating to "...development in the general field of peaceful use of atomic energy as these may relate to California water problems;...."

It was clearly the intent of the legislature that the Department assume an active role in studying and developing nuclear energy applications -- primarily power for water project pumping, but in a broader sense all applications that might benefit water resources development. These include radiological applications.

The term "program" as used herein differs from the conventional meaning of the word in Department usage. The Radiological Applications program in itself is not productive of an end result such as a plan, a design, or a recommendation for development of a water resource. Rather, it applies to the application of nuclear phenomena as an aid in measurement, identification, tracing, or detection, and is thus a device to be used in Department investigative programs or construction projects. Typical among such programs or projects are vegetative water use, aqueduct design, subsurface exploration, and construction of Thermalito Forebay-Afterbay dams.

Included in this report are brief descriptions of studies, investigations and tasks related to water resources in which radiological applications have played a part -- some successful, some unsuccessful. Plans for other related applications which are expected to be useful in future activities of the Department are outlined in a separate section of the report.

It is intended that this report series will keep those concerned with planning and development of water resources and the operation of water projects currently informed on the state of the art in radiation-related activities and will provide information on new developments which may be potentially useful in such activities.

William R. Gianelli

William R. Gianelli, Director
Department of Water Resources
The Resources Agency
State of California
September 19, 1968

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ACKNOWLEDGMENTS

The assistance provided by public agencies in helping to further t Department of Water Resources' radiological applications program has been very valuable. It has aided the Department in pursuing a more extensive program of study and application than otherwise would have been possible. F the cooperation and counsel provided by the following agencies, the Departme is particularly appreciative:

State Coordinator of Atomic Energy Development and Radiation Protection

California Department of Public Health, Bureau of Radiological Health

California Department of Industrial Relations, Division of Industrial Safety

California Division of Highways, Materials and Research Department

University of California at Davis, Department of Water Science and Engineering

University of California at San Diego, Scripps Institution of Oceanography

U. S. Forest Service, Pacific Southwest Forest and Range Experiment Station

U. S. Department of Agriculture, Agricultural Research Service

U. S. Department of Interior, Bureau of Reclamation

U. S. Department of the Army, Corps of Engineers

U. S. Atomic Energy Commission, E. O. Lawrence Radiation Laboratory

In addition, the Department appreciates the cooperation of the ind viduals and private organizations who provided generously of their time for consulting services and from whose experience in this emerging science the Department has benefited greatly. Unfortunately, the list of these many coop erators is too long to include here.

Special recognition is given Mr. Gene A. Blanc, State Coordinato of Atomic Energy Development and Radiation Protection, Professor Warren Kaufman, and others of the Departments of Engineering and Public Health at the University of California, Berkeley, for their continuing counsel and technical advice.

ABSTRACT

Radiological techniques have been applied to more than 25 investigative progr of the Department or of other agencies with which the Department has coopera These techniques range from the development of a device to measure soil com paction in earthwork construction to determination of the age of ancient tree stumps; from making in-place measurements of the physical properties of a snowbank on a mountain top to following the offshore movements of drifting sands. / Several possible future projects connected with Departmental functions might benefit from radiological applications. Among these are large-scale excavation by nuclear explosives, measurements of biological productivity of water by radioisotopes, and the use of power produced by isotopic generators. / Radiometric measurements of flow and the ratings of pumps and turbines have shown potential value and are worthy of continuing evaluatio as alternatives to the conventional methods used in the Department's water operations. / Since the Department's radiation protection program was begun, about 10 years ago, thousands of man-hours have been spent in handling potentially hazardous radioactive materials without a single reported instance of personnel overexposure.

CHAPTER I. BACKGROUND

INTRODUCTION

A major byproduct of the Atomic Age has been the substantial increase in, and ready availability of, man-made radioactive isotopes of the conventional elements. These radioactive forms of elements, which number more than a thousand, offer unique advantages for many industrial and research applications.

When incorporated in chemical, metallurgical or biochemical systems, radioactive isotopes usually behave in much the same way as do their corresponding stable cousins. But, because they emit ionizing radiation, even minute quantities of radioactive isotopes can be detected or monitored by tracer techniques.

The development of low-level counting instrument systems has kept pace with the broadening field of tracer applications. Detection limits for "tagged" elements are generally substantially lower than those obtainable in ordinary chemical or microchemical analyses. Thus, radiotracers are valuable in applications where minimal interference with the normal operation of a system is desired, or where conditions for extremely high dilution are present.

These same isotopes can also become sources of penetrating, ionizing radiation which can be used for gauging the thickness or density of materials, or used in place of X-ray sources for inspection of parts. Special fabrication techniques have made possible small, portable neutron sources. These miniature neutron generators have proved to be extremely useful in nondestructive in-place determination of moisture content of granular materials.

Another promising potential peaceful use of the atom stems directly from the nuclear devices testing program. For a number of years, studies and experiments have been conducted under the U. S. Atomic Energy Commission's "Plowshare" program to determine the feasibility of peaceful uses of nuclear explosives. Among the various potential applications of nuclear explosives studied under the program are two of interest to the Department -- the improvement of ground water resources and large scale excavation. Practical field applications have not yet been made, but the numerous studies and tests have been encouraging, giving rise to hope that applications beneficial to the Department may eventually be developed.

HISTORY OF DEPARTMENT ACTIVITIES

The Department of Water Resources initiated a program of studies dealing with radiological applications in 1958 with the recognition that this expanding field would prove potentially valuable in activities related to water resources development.

During the initial period of these studies, the objectives were to become thoroughly informed on current developments in isotope technology, and to recommend utilization of any promising isotope application techniques in the Department's water resources investigative programs.

Some of the principal activities during this early period included:

1. coordination and dissemination of information on the radiological aspects of the water quality monitoring program,

2. investigation of the feasibility of using radiotracers for determination of surface and ground water flow,

3. consultation on the radiation safety aspects of utilization of sealed radiographic sources for nondestructive inspection of materials in construction activities,

4. design and fabrication of special gauging devices for determination of in-place moisture content and density of soils,

5. development and implementation of appropriate procedures and regulations required for administration of the radiological safety aspects of radioisotope use by the Department, and initiation of a training program for personnel involved in handling radioisotopes.

As a result of the decision in 1959 to utilize Department personnel in handling radioisotopes, the Department was licensed by the Atomic Energy Commission to possess certain quantities of radioactive materials for its program. Since that time, radioisotope utilization has developed into a virtually standard technique in many investigations and shows promise of coming into more widespread use in several others.

In 1962, the State of California assumed responsibility for regulatory authority over the radioactive materials in this State from the U. S. Atomic Energy Commission. Consequently, the

Department's license was transferred to the cognizance of the State Department of Public Health.

The radioactive materials which the Department is currently licensed to possess are listed in Table 1. The twenty-one sources, which contain almost 1, 800 millicuries of radioactivity, are currently being utilized in several departmental investigations.

TABLE 1

RADIOACTIVE MATERIALS FOR WHICH DEPARTMENT IS LICENSED

Isotope	No. Sources	Possession Limit Millicuries
Hydrogen-3	4	1, 000
Cesium-137	5	15
Radium-226	6	30
Actinium-227	1	25
Plutonium-239	4	500
Americium-241	1	200

CHAPTER II. RADIOLOGICAL APPLICATIONS

SOIL MOISTURE AND DENSITY GAUGES

Two of the most effective uses in Department operations of the unique properties of radioisotopes are the determinations of soil moisture and density. Soil moisture information is mainly used in the continuing program of estimating water use of various crops. The nuclear technique for this determination has virtually replaced the former soil sampling procedures. Other important uses of moisture gauging devices have also been made. Nuclear soil density determinations are primarily used in control of placement of embankments, but have a few other interesting applications as well.

Description of Nuclear Method

The nuclear method for in-place moisture and density determinations entails the use of sealed radioactive sources. A schematic drawing of a typical device used for subsurface measurements is shown in Fig. 1. The principles of operation of the soil moisture and density measuring devices in which these sources are incorporated are described as follows:

Moisture Gauges. Certain radiation phenomena lend themselves admirably to the rapid, nondestructive measurement of moisture content of granular materials, such as soil. When a source emitting high energy or "fast" neutrons is placed in the vicinity of an hydrogenous medium, the neutrons are moderated, or "slowed", almost exclusively by collisions with nearby hydrogen atoms. Other elements with which the neutrons may collide cause a relatively insignificant loss of energy. Consequently, the number of slow neutrons produced is proportional to the density of the hydrogen atoms in the surrounding medium and is essentially independent of other chemical or physical properties. In soils, water is the principal contributor of hydrogen atoms.

The measuring device is called a "neutron probe". It consists of a detector, which is sensitive only to slow neutrons, placed close to a fast neutron source. These components are enclosed in a metal cylinder. The probe is suspended by an electrical cable which connects it to a counting device, or scaler. When the probe is lowered into a cased bore hole in the soil, pulses due to slow neutrons will register on the scaler during a fixed time interval (usually one minute). The neutron count rate

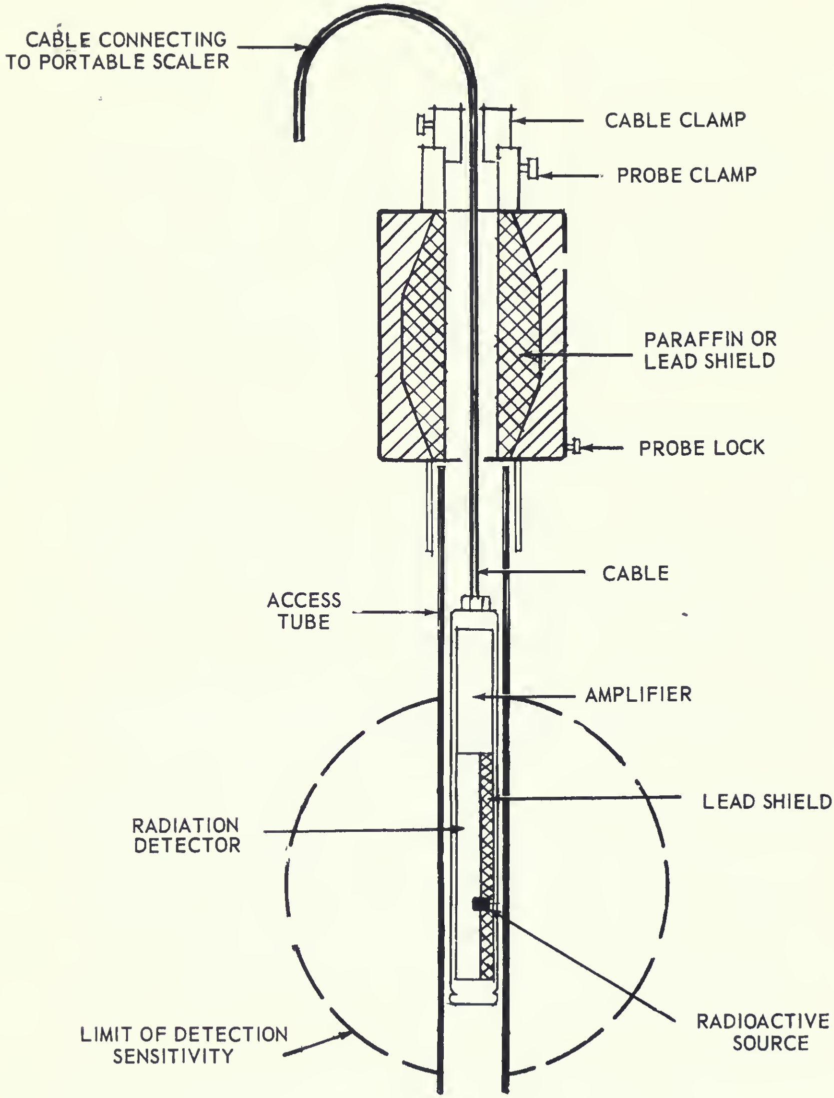

Figure No. 1. Schematic Diagram of Probe Used for Measurement of Subsurface Moisture or Density.

may then be related to soil moisture in the vicinity of the probe through a prior instrument calibration.

Density Gauges. By the application of somewhat similar principles, the use of a source of gamma radiation and a gamma detector in a density probe, the electron density of the atoms composing the soil surrounding the probe may be determined. Count rates resulting from this measurement may then be related to the bulk density of the medium in which the device is placed.

The theoretical considerations by which the moisture and density gauges operate are treated in more detail in Appendix A.

Basis for Use

Subsurface Measurements. In investigations of moisture movement in soils -- over a long period of time -- the problem exists of how to determine moisture content and density at specific points in the soil mass. The method of sampling by borings is obviously undesirable for this purpose, because, once a sample is taken at a particular point, the soil at that point is disturbed, its properties are changed, and another nearby location must be chosen for the next sample. Thus, the soil's heterogeneity introduces a variable into the measurements.

Other devices which have been used for the in-place determination of soil moisture and density have several inherent disadvantages. First, a relatively long time may be required before equilibrium between the soil and the measuring device can be attained; second, a separate calibration is usually required for each material encountered; third, the device may be accurate over only a relatively short range of moisture contents or densities; fourth, the environment may be greatly altered in placing the measuring instrument; and finally, in many instances, measurements may be made only at rather shallow depths.

Surface Measurements. In earthwork construction projects where continuous information is required if control over the moisture content and density of the soil layer being compacted is to be maintained, a rapid and accurate method which will provide values for these soil properties is desirable. This information is usually obtained by a displacement procedure. In this method, a shallow hole is dug in the soil surface, and the hole filled with sand or a fluid (such as water). By comparing the weight of the soil removed with the volume of the standard displacing material, the bulk density of the soil at that location may be calculated. The moisture content is determined by oven-drying a sample of the removed soil.

Although this procedure provides reasonably satisfactory results, it is tedious and time-consuming. Even under ideal conditions, the determinations are not completed for several hours. Frequently, when modern large earthmoving equipment is utilized on a project, the results are not available until after the soil layer of interest has been covered by several additional layers of fill. Therefore, a procedure which can deliver information more rapidly is highly desirable.

Applications

The adaptation of nuclear methods to the nondestructive, in-place determination of soil properties has provided an opportunity for significant advancement in the reliability of results, while achieving substantial reductions in time requirements for data collection. This section describes some of the applications in which nuclear gauges have proved useful.

Vegetative Water Use. A thorough knowledge of the mechanism of the consumptive use of water is essential in water development planning. One method whereby consumptive use (evapotranspiration) by an irrigated crop may be evaluated on a seasonal and monthly basis is by repetitive field measurements of the depletion of moisture from the soil.

In determining water use by a selected crop, a neutron probe is lowered into the soil through cased bore holes in the field in which the crop is growing. Moisture readings are normally made at 1-foot intervals, to the maximum depth of casing, which can be as much as 25 feet. These measurements are made periodically, between irrigation cycles, during the growing season. This procedure makes it possible to determine water content changes in the root zone of the soil, and the quantity of water depletion for any time interval selected.

The instrumentation requirements of this investigation necessitated extensive modification of commercially available equipment, or the design and fabrication of new apparatus. As specific problems arose, some novel methods were developed for their solution.

Some of these innovations have been described as Department publications or in technical journals. *

Vegetative water use measurements have been made at several field stations throughout the State. Areas in which neutron probes have been used by the Department for evapotranspiration studies include; 1) Kern County near Bakersfield, 2) Western San Luis Obispo County, 3) the Sacramento-San Joaquin Delta area, 4) the foothill areas of Placer and Nevada Counties, 5) near the Feather River in Sutter and Yuba Counties, 6) Sierra Valley in Plumas and Sierra Counties, and 7) Shasta and Lassen Counties.

Joint investigations of vegetative water use utilizing neutron probes have been conducted with the U. S. Agricultural Research Service in Santa Barbara County near Lompoc, with the U. S. Forest Service in Yuba County near Challenge, with the University of California in Yolo County near Davis, and with the U. S. Bureau of Reclamation in Fresno County near Fresno.

These investigations have been directed toward correlating evaporative demand of the atmosphere with evapotranspiration by a number of crops (pasture, alfalfa, cotton, deciduous orchards, citrus and vineyard) in several climatic zones of the State. Photographs of the equipment used for these measurements are shown on Illustrations 1 and 2. Analysis and statistical evaluation of the vast amounts of data accumulated using this procedure require electronic data processing methods. Computer programs have been developed specifically to assist in data analysis for the neutron moisture gauges.

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* "A Technique for Rapid and Precise Positioning of Neutron Depth Probes". N. A. MacGillivray and Irving Goldberg. Soil Science Society of America Proceedings, Vol. 30, No. 6, pp. 803-804. 1966.

"Effect of Neutron Source Type on Soil Moisture Measurements". Irving Goldberg, N. A. MacGillivray and R. R. Ziemer. American Nuclear Society Transactions. Vol. 10, No. 1. pp. 20-21. 1967.

"Vegetative Water Use Studies, 1954-1960". Department of Water Resources Bulletin No. 113. August 1963.

"Vegetative Water Use Studies in the San Joaquin Valley". Department of Water Resources Office Report. March 1964.

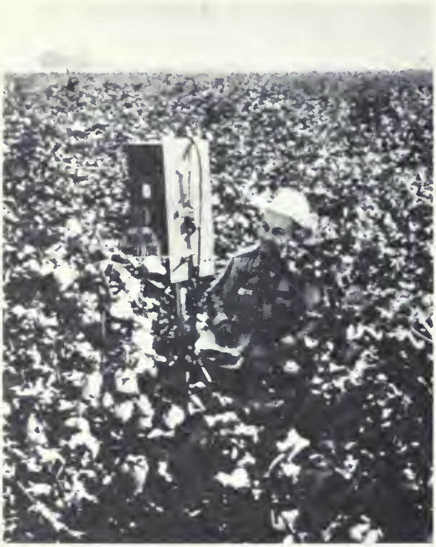
"Vegetative Water Use". Department of Water Resources Bulletin No. 113-2. August 1967.

"Measuring Moisture Near Soil Surface". R. R. Ziemer, Irving Goldberg and N. A. MacGillivray. U. S. Forest Service Research Note. PSW-158. 1967.

Illustration 1. Determining Vegetative Water Use with Neutron Moisture Meters

A. Measuring soil moisture depletion in a Kern County alfalfa field. The portable platform was devised to minimize crop disturbance during measurements.

A



B

B. Measuring soil moisture depletion in a Kern County cotton field. Ma: mum portability of equipment is required for taller row crops.

C. Measuring soil moisture depletion in a Kern County plum orchard. Disturbance of growing plants by equipment is less important with this type of crop.

C

Illustration 2. Field Use of Neutron Moisture Meters.

The neutron soil moisture meter is readily adaptable to varied geographical and climatic conditions. This enables collection of information on soil moisture depletion during the nongrowing season.

A

A. Determining soil moisture depletion in a Shasta County alfalfa field during the summer.

B

B. Same field during the winter.

Nuclear applications in the vegetative water use program have helped to explain why atmospheric demand for moisture frequently differs from measured soil moisture depletion. They have increased understanding of the influence of plant, soil and climatic factors on the vegetative transpiration process through the elimination of many of the physical limitations of soil moisture measurement which are imposed by soil sampling and other methods. Use of the neutron probe has significantly increased the number of measurements which can be made in a given length of time. The extent of soil which it is possible to measure has been greatly expanded due to the practically unlimited sampling depth which is afforded. The greater number and extent of measurements which may be made result in a more representative sample of the crop's soil moisture regime, and thus permit greatly increased confidence in the reliability of the data.

Specifically, valuable knowledge has been acquired concerning the effectiveness of irrigation water applications, the amount and extent of extraction of moisture from the soil by crops, and the effect of micro-climate, vegetative cover and soil texture on the process of evapotranspiration. Without the application of the neutron gauge in evapotranspiration investigations, the knowledge gained by the Department in the field of vegetative water use would have been much more limited.

Land Subsidence

The route of the California Aqueduct traverses extensive "shallow subsidence" areas along the west side of the arid San Joaquin Valley. This subsidence phenomenon is characterized by marked sinking of the ground surface following the application of water. Tests made in 1957 and 1958, using infiltration wells, revealed the formation of characteristic circular "stairstep" subsidence patterns, with the well structure at the center dropping as much as 25 feet from its original elevation.

Shallow subsidence could impair the operation of the concrete-lined aqueduct, which has a grade of about 3 inches per mile of length. Recognizing that some measures would be necessary to stabilize the soil prior to construction, the Department made a reconnaissance survey of the aqueduct route, and delineated potential problem areas. A test site was established near Mendota, and a series of investigations undertaken to determine the most effective feasible preconsolidation method.

Soil moisture and soil density probes were adapted to make measurements to depths of 200 feet. This equipment is shown on the photographs in Illustration 3. The instruments were used to evaluate the depth and extent of water penetration for each of the several water application techniques tried.

The test site investigations led to the selection of an optimum preconsolidation method. This method involved forming embankments along the aqueduct right-of-way with material scooped from the future location of the channel. Dikes were constructed across the alignment and water introduced, forming a series of shallow ponds. Continuous flooding for periods ranging from a few months to more than a year caused the soil to settle to a final stabilized elevation. All that remained to be done following this procedure was to allow the soil surface to dry for a period of time so that heavy earthmoving equipment might commence excavating and grading operations.

For the preconsolidation method used, the precise knowledge of the relationship of the depth and extent of the wetting front to the estimated depth of subsidable soil proved to be extremely valuable. These data were provided by routine use of the nuclear moisture and density probes during the ponding process. The measurements also indicated the rate of advance of the percolating water. This information was put to use in scheduling delivery of the relatively scarce and costly water supply, and in providing more precise knowledge of progress at each reach of the aqueduct for use in advance planning of construction operations.

For the purposes of this investigation, no method other than the use of moisture-density gauges could have provided the desired information as rapidly, accurately and inexpensively. To date, many thousands of measurements have been made, and utilization of these data has contributed materially to the design and construction of the California Aqueduct.

Delta Channel Depletion

In 1963, the Department began an investigation which incorporated a unique application of subsurface moisture gauges. The overall objective of the project was to balance the hydrologic equation for Sacramento-San Joaquin River Delta flow. This required a degree of knowledge of all the factors which contribute to inflow and outflow of water in the river system. One of these factors for which quantitative data were required was the seasonal fluctuation in subsurface water storage in the area. Accretion and release of water from the soil contributes significantly to flow in the channels. Mere

Illustration 3. Nuclear Moisture -- I

Operation of density and moist
gauges in infiltration wells, F
County (photos A and B)

A

Note the depth and extent of
subsidence

B

C

Operation of density and moisture gauges in preconsolidation ponds along the alignment of the California Aqueduct. Subsurface data is being collected from rafts (photo C) and from slant-drilled access tubes (photo D).

D

measurement of water table elevations would have supplied insufficient information for accurate determination of the total quantity of water retained in the soil. This was because of the relatively large potential storage capacity in the unsaturated surface zone of the highly organic soil. The intensively cultivated Delta area is suitable for growing a large variety of crops. The unique irrigation practices required for some of these crops prevent accurate estimation of soil moisture storage for a large portion of the Delta. Thus, field measurement of the amounts of water contained in the soil above the water table was necessary to obtain precise estimates of the contribution of soil moisture storage to the hydrologic balance.

Obtaining representative measurements of water contained in a ten-foot depth of more than a half million acres of highly productive agricultural land seemed to be a formidable task. Only through the use of the rapid, nondestructive neutron moisture gauge technique could such a vast quantity of information have been collected in the three-year period of this investigation. Approximately 500 measurement sites were established throughout the area. Three moisture meters were required. Each of the sites was gauged at least monthly.

Two problems had to be solved in order for this technique to be successful. The first was that of developing a calibration for the instruments which would apply to the highly organic soils found in most of this area, soils which are atypical of those in other areas of the state where calibration curves had been developed. A standardization procedure was developed and adequate meter calibration obtained thereby. The second problem was how to analyze expeditiously the large number of individual readings (approximately 250 per day) resulting from the measurements. For this purpose, a comprehensive computer program was developed to assist in tabulating and obtaining estimates of reliability for all the data.

The successful completion of this investigation was due, in a large measure, to the data obtained from the neutron soil moisture measuring devices.

Compaction Control

Utilization of devices containing radioactive sources for moisture and density control of earthwork structures is playing an increasingly prominent role in departmental activities. Testing started in 1963, when the first gauging instruments were purchased by the Department's Soils Laboratory. However, close liaison in nuclear instrumentation had been maintained with the State Division of Highways for several years prior to that time.

The difference between nuclear compaction control tests and most other determinations of soil properties by radiation gauging techniques is the necessity for obtaining precise data within a limited period of time. In most subsurface applications, differences in soil characteristics may be measured over some time interval -- days or weeks. The measuring site is accessible at any time, so that a questionable reading may be repeated. In earthwork construction, however, availability of the measuring site is frequently limited to a few hours. Since it is not easily subject to later verification, the test must be highly reliable the first time it is performed.

A large number of possible variations in technique can insure higher reliability of the measurements. These approaches can best be evaluated by statistical methods. A cooperative investigation was undertaken with the Division of Highways to provide such an evaluation, and was completed during the 1964-65 fiscal year. The study was primarily a laboratory exercise, although field experiments were conducted at Bethany Forebay, Whale Rock and Frenchman Dams, as well as at several Division of Highways' road projects.

Results of this investigation led to development of preliminary standard techniques which would best suit the purposes of Department projects. During the 1966 construction year, these techniques were put into practice on the Thermalito Afterbay Dam - Oroville Project. Photographs of the equipment in use on this project are shown in Illustration 4. A number of additional refinements were devised as a result of this experience, and in 1967 the improved procedures were incorporated in the measurements made on the Thermalito Forebay Dam.

The investigations which have been completed to date indicate that under certain circumstances the use of surface moisture and density gauges provides a significant improvement over conventional measurements of soil compaction. Certain future construction projects of the Department have been proposed wherein these devices will be utilized as a regular tool in the construction inspection procedure.

Snow Measurements

In 1956, the Department and the U. S. Forest Service began a joint research program to find ways to manage the snowpack of the Sierra Nevada. The two major aims were to seek ways 1) to increase the total amount of water delivered from the mountains to the streams, and 2) to delay the delivery of water from the melting snowpack until as late in the summer as possible.

Illustration 4. Nuclear Moisture -- Density
Gauges Used for Compaction Control

A

A. Surface moisture content bei
determined by device in cen
of photograph.

B. Surface density meter (lower
left) measuring compaction
at Thermalito Afterbay
embankment.

B

Essential for the determination of water yield of mountains is a more complete understanding of the dynamics of snow ripening and melt. This information is necessary in order to enable formulation of predictive equations of stream flow. Development of the radioactive snow gauges enables measurement of changes that occur in the snowpack in response to causative stimuli.

Detailed descriptions of the application of moisture and density gauges to the measurement of changes which occur in the snowpack and in the soils beneath have been published in annual reports issued by the U. S. Forest Service. The Department has assisted in the development and improvement of these measuring instruments. The two-probe gamma-attenuation snow density gauge shown in Illustration 5 makes possible frequent non-destructive density profiles of the snow pack.

Illustration 5. Two-Probe Snow Density Gauge in Use.

Observations made with this equipment have led to clarification of the phenomenon of movement of moisture through snow and have enabled the snow hydrologists to formulate predictive equations which represent significant advances in the state of the art.

Certainly, any method of comparable accuracy which allows more frequent sampling than the snow-coring procedure, which has been used for 60 years, should result in more accurate streamflow predictions.

Miscellaneous Applications

There have been a number of other investigations in which soil moisture and density gauges have been utilized. Among these are:

1. Consumptive use of water by native vegetation. Neutron moisture probes were adapted for a study of soil moisture accretion of rainfall and depletion by native vegetation in the Sierra foothill region of the Southern Sacramento Valley. Measurements were made for approximately one year (1961-62). Although the results were satisfactory, the entire study was terminated before a sufficient period of time had elapsed for meaningful trends to be established.

2. Sacramento Valley seepage investigation. In 1963-64, neutron probes were employed during the Sacramento Valley seepage investigation to measure the degree and change of soil moisture above the saturated zone. Measurements were taken before, during and after seepage occurrences. The moisture content was found to be near field capacity before the October to March seepage period and did not change appreciably during or after seepage occurrences. Although the measurements did not provide all the information the Department had hoped to obtain, they did assist in providing a better understanding of seepage phenomena, and in particular the reason for the rapid recurrence of seepage after its initial occurrence.

3. Twitchell Island investigation. In 1960-61, neutron soil moisture probes were utilized in conjunction with an intensive hydrologic investigation of Twitchell Island in the Sacramento-San Joaquin Delta area. The hydrology and soils of this area are typical of most of the islands of the Delta lowlands. As a result of the use of these instruments in this investigation, the feasibility was established for their more extensive application in the Delta Channel Depletion Study, which has been described previously in this report.

4. Sierra Valley investigation. In 1963, measurements were made with the neutron moisture probe in several areas of Sierra Valley, as part of an investigation to determine base-line soil moisture conditions of agricultural lands prior to the completion of Frenchman Dam, which is upstream from the study area. Repeated measurements of soil moisture were made over a growing season, and results obtained for soil moisture depletion were satisfactory for the limited purposes of the investigation.

5. Del Valle pipeline. In 1964, an investigation was undertaken to determine the feasibility of adapting surface soil density gauges for the purpose of locating voids in backfill around large diameter pipes. Measurements made in the Del Valle pipeline indicated that under certain conditions of soil and pipe uniformity, the nuclear method would be useful for this purpose.

6. Ground water recharge. In cooperation with the U. S. Department of Agriculture, Agricultural Research Service, studies of the recharge front movement and position of the water table in Western Fresno County were carried out in 1960-64. Neutron soil moisture probes proved to be a valuable tool in this research endeavor.

7. Soil moisture depletion studies. In cooperation with the U. S. Bureau of Reclamation, Fresno Field Division, soil moisture measurements have been made since 1967 near Fresno, in a controlled environment. The neutron probe results are being used as primary standards to calibrate direct reading evapotranspirometers, and determine their feasibility as indirect indices of evapotranspiration of crops.

ISOTOPES AS TRACERS

Basis for Use

One of the primary reasons for the usefulness of radioisotopes in tracer applications lies in the fact that infinitesimally small quantities may be detected. For example, less than 1 trillionth of an ounce of such common elements as phosphorus, sodium, calcium, cobalt, zinc, and silver may be detected with this analytical tool. With such sensitivity a very large number of phenomena can be investigated in any chemical or physical state.

The development and refinement of scintillation counters within the last decade has revolutionized many radioactivity measurements. Newer measurement techniques (e. g. pulse height analysis) have also permitted investigators to assay mixtures of radioactive materials to a degree which was not formerly considered possible. The development of low-counting-rate techniques will undoubtedly expand the number of possible analytical applications.

Methods of Use

Measurement of flow. Radioactive tracers have been used to measure surface water flow velocities, to determine the type of flow, i. e. whether viscous or turbulent, to locate leakage and determine its magnitude, and to provide information on the mixing taking place in flow systems. One of the most direct and useful of these applications in the field of hydrology is the measurement of flow rates. The three basic techniques for measuring liquid flow velocities are peak timing, dilution and total count. Detailed descriptions of the principles of these techniques are presented in Appendix B.

In addition, activation analysis methods have been developed, using both direct activation of the medium in the field, or laboratory activation of samples after they have been collected.

Age Dating. An outstanding characteristic of radioisotopes is the extreme uniformity of their decay constants, which are independent of the chemical or physical state of the material, and can provide valuable information regarding the age of certain materials. Procedures have been developed to determine the age of geological or archeological samples with reasonable precision.

Applications

Flow Measurement

Radioactive tracers enable accurate identification of flow paths and accurate calculation of flow velocities in water bodies. Two 1958 experiments demonstrated these points to the Department of Water Resources. A radioisotope of gold, in a successful experiment by Dr. D. Hull of Chevron Research Corporation, helped measure flow in the American River. Tritium, in a second successful experiment, helped the U. S. Bureau of Reclamation in consultation with Professor Warren Kaufman, University of California, to determine the extent of seepage from the Madera Canal.

As a result, the Department planned, in 1963-64, to use tritium to trace hydraulic flow in the Sacramento-San Joaquin Delta. For reasons unconnected with the technical feasibility of the experiment, the plan was not executed. The Department did make two dye releases into the Sacramento River near Freeport, however, and did measure the dye concentrations so as to delineate control areas and to determine the amount and dilution of tritium necessary.

Despite its rigid controls, the Public Health Department always has cleared proposed Department of Water Resources experiments. Nevertheless, unreasoning fear of the introduction of radioactivity into the environment does exist. Local officials sometimes do oppose the use of radioactive tracers. Public reaction to such use is oversensitive and offers an obstacle which time alone can overcome. In time, the benefit provided by radiotracer investigations will be viewed more rationally. Newer, more sensitive counting equipment has reduced the concentrations of radiotracers required for satisfactory results to values only slightly above those of the natural environment. Meanwhile, the Department of Water Resources maintains liaison with those agencies which do conduct radiotracer studies and thus keeps itself informed upon new techniques. For example, the acoustic velocity meter being used in river channels, canal pump lines and penstocks requires a primary calibration standard. Isotope flow measurement techniques may be a promising method of providing this calibration.

Pump and Turbine Rating

In hydroelectric powerplants, the efficiency of the turbines is determined by measuring or calculating the rate of water flow through the turbine for a particular head and rate of electrical power production. Accurate measurements of power production are relatively simple, but measurements of the corresponding water flow rate to the same degree of accuracy are more complex. Because turbine ratings are used not only to determine turbine efficiency but also to schedule reservoir releases, and in some cases to indicate total streamflow, turbine flow must be measured accurately. Essentially the same fundamental principles as described above are involved in rating pumps.

Some experimental work on the use of a radiotracer method for rating hydraulic machinery has been done, primarily by the Bureau of Reclamation. The flow measurement method involves introducing the tracer into the pump or turbine flow and observing the passage of the tracer at some downstream point. The method of computation of flow from the data obtained in this manner is a comparatively simple operation. Whether it has clearcut advantages over other methods cannot be established at this time, but the technique warrants periodic consideration to evaluate any improvements that might be developed.

Subsurface Flow Measurement

During 1964-65, the Department investigated the use of radioisotope tracers to determine subsurface conditions. During foundation drilling at the left abutment of the Castaic Damsite, high water losses were occasionally experienced in certain of the drill holes. Explanation of those losses was considered to be a necessary phase of foundation exploration.

Sodium-24 was used as a tracer material to determine rate and direction of flow of waters between appropriately located drill holes. This radioisotope may be detected at relatively low concentrations and has a short (approximately 15 hour) half-life. These characteristics make it suitable for use as a field tracer with virtually no attendant health hazards if reasonably simple safety precautions are observed.

Approximately 9 millicuries of sodium-24 diluted in 10, 500 gallons of water were introduced into a drill hole in five separate injections. Measurements in adjacent drill holes with a logging tool containing a radiation detector resulted in no indications of increased radioactivity above natural background in any of the holes. Photographs of the procedure are shown in Illustration 6.

Although results of this experiment were inconclusive, information was obtained which will prove valuable in our future applications of subsurface tracers. On the basis of the results of measurements within the injection hole, calculations were made which would account for the failure to detect activity in the other measuring sites. The principal cause was a combination of subsurface physical conditions which could not have been predicted in advance. The published report* summarized the knowledge gained from this experiment. Several recommendations were made which, if followed, will lead to more conclusive results in future investigations of this type.

Watershed Management

A rather dramatic use of tritium as a tracer was demonstrated in 1966 on the Department sponsored watershed management research project in Placer County as conducted by the University of California, Davis, through the Water Resources Center. In this experiment water was tagged at the water table 70 feet below the ground surface. Within days, the tracer was detected in the leaves of the nearby oak trees.

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*"Application of a Radioactive Tracer to Ground Water Flow - Left Abutment - Castaic Damsite". J. S. Bigelow and Irving Goldberg, Department of Water Resources Office Report, Division of Design and Construction. July 1965.

Illustration 6. Radioactive Tracer Application at Castaic Damsite

A. Withdrawing measured quantity of radioisotope from shielded container.

B. Mixing tracer in carrier salt solution.

C. Injecting tracer in ground from tank truck.

D. Logging observation well with scintillation detector.

Tracers have been used in U. S. Forest Service Watershed Management Research in the snowlands, cooperatively supported by the Department, to determine the direction and velocity of water movement in a tree from the root, through the trunk, and to the leaves. The path of water movement was found to be rigidly linear and unbranching.

Tracers have also been used to follow the path of melting water through a snow pack. It was found that such water does not move vertically only. In denser layers of snow, movement was downslope within the dense layer, and with some horizontal movement sideways. In the less dense snow layers, the motion was vertical.

Analysis of Water Quality

There are at least two types of applications in which radiological techniques are found to be of benefit to the Department's water quality investigation program. One is the measurement of radioactivity in waters as part of the water quality monitoring program. The other involves use of radioisotopes in specific water quality determinations.

1) The Department's water quality data program has included reporting of radioactivity in raw water samples since the mid 1950's. The radiological applications program has provided consultation and recommendations concerning technical aspects, such as statistical significance, of low-level radioactivity determinations. In recent years, radionuclide analyses made by the State Department of Public Health on treated waters on other items for human consumption have, to a large extent, replaced this activity.

The Department's reports provide a valuable addition to the record of radioactivity in the State's waters for the period antedating the State Health Department's more extensive participation in this field. The Department's data program has revealed a few instances of inadvertent concentration and release of natural radioactivity into water supplies by chemical processing activities. As a result, radioactivity might have exceeded annual limits set by State and Federal Radiation Protection Guidelines. These results were brought to the attention of the appropriate authorities, and the operations contributing to the releases were terminated prior to the buildup of radioactivity to undesirable levels.

2) There are two analytical determinations directly connected with Department water quality investigations in which radioactive materials are used. One is the use of tritium in

analytical instruments for the identification of pesticides. These instruments have been operated by analytical chemists in the Technical Services Office of the Department for several years. The second is the carbon-14 bioassay technique for determining biological productivity of waters. This procedure employs direct measurement of the growth of microscopic plants under natural conditions of temperature and light as an index of the "fertility" of waters.

The carbon-14 bioassay procedure has a potentially large application as one of the biological monitoring and control procedures which are to be maintained for the State Water Project. In addition, increased interest in the preservation of our natural water supplies from environmental contamination may lead to a monitoring program in several lakes and streams throughout the State.

Age Dating

An important area of knowledge, on which very little positive information is available, is the field of paleoclimatology. Precise knowledge of the long-term climatic changes of western North America could assist in predicting future trends, and would thus be valuable for water development planning investigations. The Department has sought this type of information in a number of ways, one of the most significant of which has been the maintenance of close contacts with some of the foremost authorities in the field of age-dating of specimens containing carbon.

As an example of such cooperative efforts, in 1962 samples of wood from tree stumps were submitted to the Scripps radiocarbon laboratory in San Diego for age determination. These samples had been collected on the western shore of Lake Tahoe when the lake level was at its lowest point in several decades. It was possible at that time to recover wood samples from stumps of trees which apparently were killed by a rise in the lake level during prehistoric times. The age of these trees could possibly provide valuable information concerning a major climatic change in that area.

The radiocarbon dates determined by the laboratory* indicated that the trees grew to maturity and were subsequently preserved

* "La Jolla Natural Radiocarbon Measurements". C. L. Hubbs, G. S. Bien and H. E. Suess. American Journal of Science, Radiocarbon. Vol. 5. p 262. 1963.

in the lake waters for nearly 5,000 years. This result was unexpected due to the remarkable state of preservation of the wood. From this information, and from supplementary geological data, the hypothesis was presented that no major climatological changes which would have lowered the level of Lake Tahoe from its present elevation for any significant period of time could have occurred in at least the last 5 millennia. It was concluded that the rise in lake level which killed the trees along the shoreline was more likely due to diastrophism than to increased precipitation.

Specimens of wood from Eagle Lake, and from archeological findings along the California Aqueduct construction sites, have been submitted to the radiocarbon laboratory for age determination. Results of these analyses* have been less dramatic, but they have assisted in confirming some previously postulated theories concerning the past climate and geology of those areas of the State.

Radiocarbon dating is thus seen as an important aid to the derivation of rational bases for water resources development planning.

Stable Isotopes as Tracers

Although the radiological applications program deals principally with investigations concerned with utilization of radioactive materials, there are several important investigations associated with this program which stable rather than radioactive isotopes are used.

1) Recent studies have indicated that considerable information regarding the source and history of surface and ground waters may be obtained by analyses for the stable isotopes of hydrogen and oxygen normally present in such waters. These isotopes include hydrogen-1 and hydrogen-2 (deuterium), and oxygen-16, oxygen-17 and oxygen-18. Because of differences in volatility caused by the normal distribution of these isotopes in water, there is a tendency to enrich waters, which are subject to free evaporation, in the heavier of these isotopic species. Similar phenomena govern the condensation of water vapor which falls as precipitation. Thus, there is a natural fractionation of the stable isotopes of hydrogen and oxygen in the hydrologic cycle.

A knowledge of the proportion of each of these isotopes in a sample of water can be a valuable indication of the source of that water. Instrumentation is now available to perform rapid

* "La Jolla Natural Radiocarbon Measurements". C. A. Hubbs, G. S. Bien and H. E. Suess. American Journal of Science, Radiocarbon. Vol. 4. p 231. 1962 and Vol. 6. pp 604-610. 1964.

and relatively inexpensive oxygen isotope analyses of water. Studies devoted to refinement of this technique and investigations of the source and history of water supplies have been conducted at the Scripps Institution of Oceanography. The Department of Water Resources is closely following these studies, which are of great value to the understanding of fundamental hydrologic processes.

2) Activation analysis has the potential to prove valuable in water resources applications. This method involves:

a) introducing of a stable tracer into a system;
b) allowing the process which is being measured to take place;
c) removing a sample from the system;
d) making the stable tracer artificially radioactive by neutron bombardment;
e) making a quantitative determination of the radioactive species by conventional counting techniques.

This procedure combines all the advantages of the radioactive tracer technique with the additional benefit of minimal health hazards to operating personnel and to the general public. Although the principal commercial applications of activation analysis are in industrial and forensic microchemistry, its use in large scale field studies involving water movement may some day be common. The principal shortcoming of the method at this time is the relatively high cost of the analysis, which is only partially offset by the low cost of equipment and materials in the actual conduct of the experiment. Nevertheless, there are investigations in which activation analysis may be the only economically feasible way to obtain the desired results.

3) The detection and measurement of tritium deposited as fall-out from nuclear weapons testing provides a means for tracing the flow of surface and subsurface water. Tritium is not a stable isotope, but decays radioactively with a half-life of approximately 11 years. The analysis of water for "bomb tritium" has proved to be a valuable method of determining the recent history of the water. Such measurements have been used to provide useful information on the rate and direction of subsurface water movement, and on the distribution of surface waters.

Littoral Transport Studies

The Department of Water Resources has been directly involved in a continuing series of tests using radioisotope-tagged sand to determine the mechanics of offshore movement of sediment, particularly around headlands. This study, called RIST (Radioisotopic Sand Tracer) is under the combined sponsorship of five agencies: U. S. Army, Navy, Air Force, NASA, and the DWR. Additional funds have been provided through a grant from the Atomic Energy Commission.

Very little direct field information is available about the complex mechanism of sediment transport phenomena in the vicinity of headlands. These processes are particularly significant in their relationship to the serious problem of beach erosion.

The techniques oı removing, labelling, and replacing particles of sediment so that their offshore movement may be traced were developed as the first phase of this study. In April, 1957, a field evaluation test was conducted at Cape Kennedy, Florida. This resulted in development of the following procedure, which was subsequently used in two field tests near Point Conception, California.

Several hundred pounds of sand were collected from the test area, and shipped to Oak Ridge National Laboratory in Tennessee. There the sand was placed in a furnace and heated to 900° C in an atmosphere of radioactive xenon-133. The gas combined with the sand crystal structure, resulting in a supply of sand tagged with a chemically inert substance that had an effective half-life of 2.7 days. The tagged sand was shipped back to the injection site by air. One reason for the selection of xenon-133 as a tracer was that it will not interfere with the ecology of the marine environment.

The monitoring system incorporates a solid state detector, which was mounted inside a cylindrical "detector vehicle" which rolled along the ocean bottom as it was towed by an amphibious vehicle (LARC) borrowed from the U. S. Army Mobility Equipment Command. The readings of the detector, including radiation, position, and time, were recorded on an 8-channel punched tape located in the LARC. The electronic system enables differentiation between vertical and horizontal dispersion and mixing of the tracer sand.

The first pilot test in California was made commencing June 13, 1967, at the mouth of the Santa Ynez River near Vandenberg AFB. Initially a point drop of a small amount (approximately 100 liters containing 10 curies) of the tagged sand was made, primarily for purposes of instrument calibration, establishment of measuring grids, and refinement of handling techniques. At a later date, a linear source, normal to the beach, was injected from the high tide line to a 20-foot depth, and tracing operations were again carried out.

A second field injection was made commencing on November 27, 1967, in the vicinity of Government Point, east of Point Conception. Photographs of the equipment used in that test are shown in Illustration 7.

The progress of the RIST study is considered successful to date, being marked by significant accomplishments in its first two years. Results of the field studies have indicated that the basic tools are now available with which to trace movement of material around a headland, and thereby study the mechanics of its transport. Much work remains to be done, however, to refine the analytical techniques, and to further quantify the results of the measurements.

Underground Nuclear Explosives

An application of nuclear energy of potential value to the State is that of underground nuclear explosives. Consideration of such applications is included in this program, though in a strict sense a nuclear explosive is not in the category of radiological applications. The latter depend for their usefulness upon the radioactive properties of the atom rather than upon the release of energy as occurs in an explosion.

An underground explosion might increase the available water supply by facilitating recharge of an aquifer. This might be done by increasing storage capacity or rock permeability, or by breaking through a barrier to interconnect adjacent aquifers. Nuclear explosives can also be used for large scale excavation, an application which has been experimentally demonstrated at the AEC Nevada Test Site.

An underground explosion might also produce a great amount of recoverable heat at moderate cost. The heat could possibly be released at a controlled rate by use of a transfer agent, such as water or gas, and used for the production of power, or in the form of heat for the conversion of salt water to fresh water.

Study and experimentation in the peaceful uses of nuclear explosive devices were initiated in 1957 at the E. O. Lawrence Radiation Laboratory (operated by the University of California) at Livermore as part of the AEC Project Plowshare Program. In addition to the possible applications relating to ground water, other uses being investigated by the laboratory include (1) excavation, (2) isotope production, (3) recovery of oil from shales and tar sands, (4) mining, and (5) applications to scientific studies in seismology, geology, and special chemical reactions.

Illustration 7. Radioisotope Sand Tracer Experiment
Near Point Conception, California

A. LARC containing tagged sand and detector preparing to embark on a sand tracer run.

B. Amphibious craft returning t[o] beach after tracer run.

C. LARC with ramp down, showing detector sled (left center) and drum containing tagged sand (just right of sled).

The Department has participated in discussion with members of the laboratory staff concerned in Project Plowshare studies in an attempt to evaluate effects and possible benefits of an underground nuclear explosion in an aquifer. Insufficient information is available, however, to assess the effects of such an explosion on either the geological formations in which ground water occurs or the water itself, and further investigative work is not planned by the Department at this time.

A study of a project of this type, which the Department will observe with interest, will be conducted jointly by AEC and the Department of the Interior for Arizona beginning in July 1968. This study, to last about a year, will cover the feasibility of nuclear explosives for water management purposes, possible sites for such explosions, cost analyses, and recommended courses of action. Radioactivity and legal problems of water rights will be stressed in the study.

The possibility of producing controlled power or heat from an underground explosion appears quite remote. Some preliminary studies of the technical feasibility and economics of a process for transfer of residual heat from an underground explosion to water have been made. These studies indicate the probable costs to be quite high.

In 1961, the Department entered into an agreement with the Atomic Energy Commission to conduct a study of the application of nuclear explosives to the West Side Conveyance System, a feature of one of the alternative plans for development of water in Northern California. The study* indicated that (1) conveyance channels could be excavated by nuclear explosions, at a significant savings in overall cost of the System, and (2) by the projected date of construction (1985 or 1990), the nuclear devices could be detonated with confidence and safety.

Potential Future Radioisotope Applications

In addition to those current investigations described in this report, there are other areas of interest, some of which are extensions of present applications, in which the feasibility of radioisotope use will be studied in detail. These are summarized as follows:

Soil Moisture and Density Studies. Nuclear gauging devices, which have proved to be useful and valuable tools for nondestructive testing, will undoubtedly find more extensive and varied applications in future Department activities. Some possibilities are:

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*"Excavation for Water Conveyance with Nuclear Explosives", J. W. Keysor and M. B. Andrew. Proceedings, Third Plowshare Symposium. TID-7695 pp. 363-370. April 1964.

1) Use of subsurface moisture gauges in an investigation of salinity conditions in the Suisun marsh area, preliminary plans for which are under way;

2) Evapotranspiration measurements of additional crops of importance of California agriculture;

3) The control of preconsolidation using subsurface moisture and density gauges in any additional areas of shallow subsidence along the route of the California Aqueduct or other features of the State Water Project;

4) Nuclear compaction control equipment in embankments in those projects for which it is found most suitable. The most likely of these are thought to be the Clifton Court Forebay and possibly the Castaic Dam.

Surface and Ground Water Tracer Studies. Conventional methods have been selected for rating the Department's pumps and turbines and for measuring flow in the Aqueduct. However, the results of a radioisotope testing program for such ratings, which is being carried out by the Bureau of Reclamation at Denver, have been encouraging. If the superiority of these methods is established, they may some day be adapted for use in future Department testing and measurement program.

Underground flow experiments utilizing radiotracers have a broad potential in future Department activities. Among those projects which have been mentioned for possible future use are:

1) Measurement of ground water flow at proposed damsites,

2) Tracing of sewage effluents in artificial recharge plots,

3) Measurement and tracing of seepage of drain waters from regulatory and emergency storage reservoirs.

Several applications of neutron activation analysis have potential in Department activities. In any instance (such as measurement of aqueduct water flow close to turnouts) where there may be public oversensitivity to direct radioisotope injection, this technique is both possible and feasible, though probably more costly than the alternative. Activation analysis has also been proposed as a method for delineating seawater intrusion areas. This kind of analysis may also have some direct application in those instances where contamination of water supplies by small traces of pollutants is suspected.

Water quality studies would certainly benefit from more extensive applications of the carbon-14 uptake technique. This method has been proposed for use in the continuous monitoring of biological productivity in reservoir and aqueduct waters.

Age-dating by isotopic content should have considerably more value as the importance of the dependence of long-range water supply forecasts on past history becomes more widely recognized.

Isotopic tracer techniques have been suggested for detection or tracing of leakage from pipelines embedded in levees.

Isotopic Power Generators. The recent development of radioisotope power systems is being followed with interest, since this application has potential for use in Departmental activities. The AEC-sponsored SNAP (Systems for Nuclear Auxiliary Power) program has as its objective the use of various radioisotopes for electric generators. SNAP generators with a power range of from 25 to 100 watts have been developed and are being tested to evaluate their reliability. An AEC-sponsored engineering design study is presently being made to assess the needs for isotopic powerplants in the 1- to 10-kilowatt power range. Compact isotopic plants could possibly fulfill moderate power requirements in the more remote areas of the Department's operations; for example, in the flood forecasting and Aqueduct operation and maintenance activities.

CHAPTER III. RADIATION PROTECTION PROGRAM

INTRODUCTION

In the United States the possession of radioactive material by any person or organization is prohibited unless authorized by a license granted either by the Atomic Energy Commission or by a State which has been granted regulatory control by the AEC. In 1962, the State of California, through its Department of Public Health, assumed authority to license and otherwise to exercise regulatory control over most kinds of radioactive material within the State's boundaries by agreement with the Commission.

In seeking approval for a license to use radioactive material, an applicant must establish that "his specified personnel are qualified by reason of training and experience to use radioactive material... in such a manner as to provide reasonable and adequate assurance of protection to health, life, and property;"* and that "the applicant's equipment, facilities, proposed uses and procedures are such as to provide reasonable and adequate assurance of protection to health, life and property;... "*

Thus, a necessary adjunct to initiating and conducting any investigation involving use of ionizing radiation is the acquisition of the specialized training necessary for the establishment of an adequate radiation protection program.

HISTORY

In 1959 the Department of Water Resources applied for its first license to possess sources of radiation. Because of AEC's requirement for internal control and management of radiation, the position of "Radiological Operations Officer" was established, and the authority to be exercised by the individual appointed to that position was delineated in the Department's Administrative Manual.

As uses of radioisotopes increased, the responsibility for management of the Department's radiation protection program also broadened. In 1960, the Department was authorized, by amendment to its license, to conduct its own radiological training program, and to designate those employees thus qualified to handle radioactive

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*Title 17, California Administrative Code, Chapter 5, Subchapter 4. California Radiation Control Regulations, Sec. 30194 (a) and (b).

materials. Individuals authorized by the Department's internal training program have been incorporated by reference as "individual users" in the Department's Radioactive Materials License.

At present, the Radiological Operations Officer is responsible for:

a) Furnishing technical assistance in the planning and execution of work which involves the use of radioactive materials.

b) Qualifying and designating departmental employees as radiological operators.

c) General surveillance of all radiation activities to assure safe use of radioactive materials throughout the Department.

d) Distributing and processing personnel monitoring equipment.

e) Supervising and coordinating the medical examination program for radiological operators.

f) Storing, issuing, and disposing of and supervising the shipping of radioactive materials.

g) Reviewing requests for equipment containing radioactive sources.

h) Establishing and supervising decontamination procedures.

i) Providing assistance to the Training Officer in establishing and conducting training in departmental radiological operating procedures and practices.

j) Representing the Department in contacts with manufacturers of radiation materials and equipment and with regulating agencies. *

In addition to the above duties, the Radiological Operations Officer serves in a Radiation Protection liaison function with other agencies

* DAM, Section 3843.3

or contractors in programs involving use of radioactive materials in which the Department is a cooperator or a sponsor.

In the nine years during which the Department has been licensed to use radioactive materials, no case involving injury by or overexposure to radioactive materials of Department personnel or contractors has occurred. The occasional conditions of potential radiation hazards have been corrected following recommendations of the Radiological Operations Officer.

As of the end of fiscal year 1967-68, almost 40 Department employees were required to participate in the personnel monitoring program, due to being engaged in work in which exposure to ionizing radiation was a possibility.

The Department is continuing to maintain close working relations with state and federal regulatory authorities in the field of radiation protection.

CRITERIA FOR CONDUCTING FIELD RADIOTRACER EXPERIMENTS

One of the questions frequently asked by managers of programs which could benefit from application of a field tracer experiment deals with the possible complexity of securing permission to conduct such an experiment. On the basis of experience gained in securing such permission the general requirements for an experiment of this type are discussed and summarized below.

The State Legislature has set up a number of criteria for approval of field projects involving use of isotopes in California*. The intent of these requirements is that any tracer study:

1) provide information of substantial public interest,

2) be performed by persons competent to handle and use the radioactive material safety and with due regard for potential effects on public health,

3) has been planned so as to impose the least exposure to ionizing radiation consistent with achieving the study's desired objectives, and

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* Division 20, California Health and Safety Code. Chapter 7. Section 25608.

4) will not likely expose any person to ionizing radiation in excess of guide levels published by the Federal Radiation Council.

The law also provides for the full and complete disclosure of details of the study to all appropriate local and state authorities, and the presence of a representative of the State Department of Public Health during the procedure.

It is the policy of the Health Department to judge each proposal for such a study on its own merits, with particular emphasis on minimizing potential exposure. Assuming all the above listed requirements are fulfilled, a license is issued for possession of only enough of the radioisotope to perform one study. Separate license applications must be made for each individual experiment.

In the use of short-lived radionuclides for tracing surface water flow, the technology has advanced to the State where few obstacles should stand in the way of obtaining full approval of Public Health authorities, providing the previously cited criteria are met.

FUTURE PLANS

Although the Department's radiation protection program was developed primarily for its employees who are directly involved in using sources of radiation, attention is also being given to those individuals who may be incidentally exposed to radiation during performance of duties unrelated to handling radioactivity. For example, Department inspectors may work at construction sites where industrial radiography is being performed. Criteria for monitoring these individuals are being developed and recommendations for use of personnel monitoring devices are being prepared.

It is anticipated that the need for a radiation protection program of the type presently in effect will be required in essentially its present form as long as the Department is involved in investigations which employ radioactive materials. The cost of this program is estimated to be approximately $4,000 per year.

APPENDIX A

PRINCIPLES OF SOIL MOISTURE AND DENSITY MEASURING DEVICES

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PRINCIPLES OF SOIL MOISTURE AND DENSITY MEASURING DEVICES

MOISTURE GAUGE

Theory of Neutron Scattering

Unstable isotopes spontaneously disintegrate and release energy in the form of alpha or beta particles and/or gamma radiation, and these radioactive isotopes can be used as a source of one or more desired radiations.

If an alpha-emitting isotope is intimately mixed with a finely divided light element, such as beryllium, the bombardment of the atoms of the light element by the alpha particles will result in the ejection of a neutron from the nucleus. This fast neutron has a mass approximately equal to that of a hydrogen atom, has an average kinetic energy of 4 or 5 million electron volts (mev), and is electrically neutral.

If a point source* of fast neutrons is placed within a homogeneous medium, the neutrons travel radially outward from the source until they collide with atoms of the surrounding material. In these collisions the neutron may be absorbed by the nucleus of the atom, or it may be elastically or inelastically scattered. For the elements contained in soils, the cross section, or probability of collision, for elastic scattering is predominant. The elastic scattering collisions conform to the laws of Newtonian mechanics, and it can be shown that a fast-moving neutron will lose energy in a collision with a slower moving atom.

In a mass of soil, a fast neutron is slowed, or moderated primarily by a series of elastic collisions until its kinetic energy approaches the average kinetic energy of the moderating atoms, as determined by the ambient temperature. When a neutron has the same energy as the surrounding atoms, it is called a slow or thermal neutron. In the thermal region a neutron may gain or lose energy with equal probability, so the thermal energy is a lower limit to the slowing process. Thermal neutrons do not have a definite velocity direction with respect to the source, but move in a random fashion throughout the medium. Their motion can be described by the principles of diffusion theory.

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* Actually, a source of small but finite dimensions is used instead of the mathematical point source postulated here.

Hydrogen is more effective in slowing fast neutrons than any other element; therefore, if an instrument which can detect slow neutrons, but which is insensitive to fast neutrons, is placed near a source in a medium such as soil, the counting rate of the detector will primarily be due to the hydrogen content of the soil. Hydrogen is a good moderator because its cross section for elastic scattering is large, and because in a collision with a hydrogen atom a neutron may lose a large fraction of its kinetic energy. This latter phenomenon occurs because the mass of a neutron is about the same as that of a hydrogen atom, and in a head-on collision with a stationary hydrogen atom, a neutron may transfer virtually all its energy and momentum to the hydrogen nucleus.

Since neutron moderation by other elements in the soil is small, and since in normal soils most of the hydrogen present is contained in the soil moisture, the detector response can be calibrated in terms of moisture content. Although the mineralogical, or grain structure and aggregation of soils vary widely, the elemental composition of most soils is remarkably similar. As the neutron scattering properties of soils depend upon the elemental composition (diffraction effects due to variation in crystal structure being neglected) a single calibration curve will serve for most soils.

The presence in a soil of significant large quantities of a strong neutron absorber such as boron, lithium, cadmium or chlorine may introduce errors in the moisture determination. Likewise, measurements of moisture in soils containing a high percentage of organic matter will contribute to the total count rate. The hydrogen contained in the crystal lattice of clay minerals will contribute in the same manner to the count rate. In general, soils containing large amounts of organic matter or clay contain proportionally larger amounts of moisture in the field condition. For this reason, the effect of the hydrogen from sources other than water becomes relatively small in actual practice.

DENSITY GAUGE

Theory of Gamma Ray Scattering

The mass density of soils or granular materials is measured by counting the gamma rays which are backscattered to a detector by collisions with atoms of the material.

The scattering of gamma rays is somewhat analogous to the scattering of neutrons in that gamma photons suffer a change of direction and a loss of energy in a collision. Unlike neutrons, which interact with atomic nuclei, gamma rays are scattered primarily by electrons of the atoms in their path. Although the detectors commonly employed in density probes are somewhat energy dependent, the difference in energy of the source radiation and the scattered radiation is not sufficiently great to allow the detector to distinguish between the two. For this reason, it is necessary to shield the the detector from the source, so that only gamma rays scattered around the shield by collisions with atoms of the medium being measured will enter the detector.

If the source and shielded detector are placed in a vacuum, the gamma rays will travel radially outward from the source and not reach the detector. If the region around the source contains atoms of scattering material, some of the gamma rays will be scattered into the detector by single collisions and a definite count rate will be observed.

As the numerical density (number of atoms per unit volume) is increased, the probability of scattering by single collisions increases, and the count rate increases. However, as an increase in numerical density interposes a greater number of atoms between the point of the first collision and the detector, there is an increase in probability that the gamma rays will be scattered away from their path to the detector by secondary collisions. This secondary scattering also results in significant energy loss to the gamma rays, and further decreases the probability of their ultimate detection. Thus, the count rate at first increases with density, reaches a maximum, and then decreases with increasing numerical density. The mass density of a homogeneous material is proportional to the numerical density, so the above-described scattering phenomenon can serve as a measure of mass density.

APPENDIX B

PRINCIPLES OF FLOW MEASUREMENT WITH RADIOISOTOPES

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PRINCIPLES OF FLOW MEASUREMENT WITH RADIOISOTOPES

Flow Measurement by Peak Timing

In the peak-timing technique, in order to obtain sharply defined peaks, the radiotracer is injected quickly at a point close to the section in which the velocity is to be timed. The tracer is then observed in transit down the stream at two points spaced a known distance apart, and in a uniform channel, and the time of passage of the peak of the tracer wave is determined using two submerged detectors, connected usually to a ratemeter and a recorder. The measured time interval is divided by the distance between the observation points to calculate the linear flow rate. If the mean area of the channel between the two points can be estimated or calculated, the volume flow rate may be determined.

Accurate results can only be obtained with the peak timing technique for highly turbulent flow with effectively a flat velocity profile.

Flow By Dilution

The dilution method utilizes the fact that the concentration of tracer in a stream resulting from the continuous bleeding at a known rate of a tracer into the stream will be inversely proportional to the relative flow rates of the stream and the bleeder, if the tracer uniformly mixes with the flowing liquid. The concentration of the tracer in the stream can be determined by measuring either the beta or gamma activity in samples taken from the stream or by using a detector submerged in the stream.

The disadvantage of the dilution technique is that it requires uniform mixing, which involves injecting across the total surface area of the flowing fluid and usually mixing the fluid in a pump.

Flow by Total Count

The total count method is based on the measurement of the total number of counts from the tracer as it flows past a detector.

The total count bears a simple inverse relation to the flow rate and this property makes it useful for measuring flow rates in any type of flowing system for which a calibration constant can be determined.

In the total count method, a measured quantity (A) of radiotracer is introduced into the flowing stream; a counter fixed in, or near, the stream some distance below the injection point accumulates a certain number of counts while the tracer is passing. This number of counts (N) is independent of the distribution of the tracer along the stream, although the tracer must be uniformly distributed through the cross section of the stream so that the final count can be converted to the flow rate by use of a determined constant.

The value of N is inversely proportional to the flow rate, Q, since a slow-moving stream allows more time for counts to accumulate. In addition, the more tracer used, the more counts are recorded. Thus N is directly proportional to A, the amount of isotope.

Therefore,

$$N = \frac{AF}{Q} \qquad \text{or} \qquad Q = \frac{AF}{N}$$

where the proportionality factor F is a constant which is characteristic of the isotope, the counter, and its geometrical relationship to the stream. The numerical value of F can be determined in the laboratory by exposing a counter to tracer solution in the same geometrical arrangement as in the field test, to find the counting rate that corresponds to a certain concentration of tracer. Calibration for large canals or streams is done in a large tank of known volume where the boundary walls are maintained at a distance of several feet from the detector. This simulates the infinite conditions existing in the large body of water.

The basic flow formula in hydraulics is Q = AV; with isotope measurement this becomes $Q = \frac{AF}{N}$, where

A = isotope or tracer quantity
F = calibration factor, and
N = the net total number of counts

The calibration factor $F = \frac{R \text{ counts/sec}}{C \text{ mci/ft}^3}$, where R = counting rate and C = concentration of tracer.

These units can be rearranged so that the dimensions of F are those required in the basic equation

$$\frac{F \text{ counts}}{\text{mc}} \cdot \frac{\text{ft}^3}{\text{sec}} \cdot \frac{A \quad \text{mcl}}{N \text{ counts}} = Q \frac{\text{ft}^3}{\text{sec}}$$

In determining leakage rates, the equation can be rewritten

$$A = \frac{NQ}{F}$$

APPENDIX C

DEFINITIONS

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<u>Activation</u>: The process of artificially inducing radioactivity in a stable element, usually by bombarding with neutrons.

<u>Alpha particle</u>: A basic form of radioactivity consisting of 2 protons and 2 neutrons, hence identical with the nucleus of the helium atom.

<u>Beta particle</u>: A negatively charged elementary particle identical to the electron. A basic form of radioactivity.

<u>Curie</u>: The quantity of a radioactive substance having a radiation emission equal to that of one gram of radium, symbol Ci. A millicurie (MCi) is one-thousandth of a curie.

<u>Decay (Radioactive)</u>: The process of nuclear disintegration, by which an atom seeks stability. It is characterized by emission of particles (e. g. alpha or beta) or electromagnetic radiation.

<u>Decay constant</u>: An expression of the rate of radioactive decay of a substance.

<u>Electron</u>: An elementary particle carrying one unit of negative electric charge and usually considered as orbiting around the atomic nucleus. Electrons determine the chemical behavior of the elements.

<u>Evapotranspiration</u>: The quantity of water transpired by plants, retained in plant tissue, evaporated from plant foliage from surrounding surfaces and from adjacent soil, in a specified time period. Usually expressed in depth of water per unit area. As used here, evapotranspiration is synonymous with consumptive use.

<u>Gamma ray</u>: A penetrating form of radiation originating in the nucleus of some atoms during radioactive decay. Equivalent to high energy X-ray.

Isotope: One of two or more forms of an element having the same atomic number, identical in chemical behavior but differing in atomic weight.

Neutron: An uncharged elementary particle contained within the nucleus of all atoms except hydrogen-1.

Nucleus: The core of an atom around which the electrons revolve. It is composed of protons and neutrons and has a positive charge equal to the number of protons.

Proton: An elementary particle in the atomic nucleus, carrying one unit of positive electric charge. Mass is approximately that of the neutron.

Radioactivity: The spontaneous disintegration of unstable atomic nuclei accompanied by the emission of radiation - alpha particles, beta particles, or gamma rays.

Radioisotope: Radioactive isotopes of chemical elements.

Scintillation counter: An instrument that detects and measures ionizing radiation by means of light flashes induced in certain materials called phosphors. The flashes are converted to electrical impulses which may be counted by a meter.

Tritium: An isotope of hydrogen having atomic mass 3.